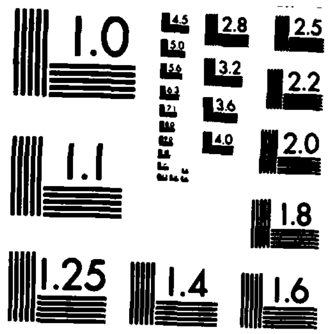
AD-A154 119 COMPUTATIONAL METHODS IN ADVANCED STRESS AND DURABILITY 1/1
ANALYSES..(U) GEORGIA INST OF TECH ATLANTA CENTER FOR
THE ADVANCEMENT OF CO.. S N ATLURI NOV 84

UNCLASSIFIED GIT-CACM-SNA-84-48 AFOSR-TR-85-0381 F/G 12/1 NL

END
FILMED
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD-A154 119

DTIC FILE COPY

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(2)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: AFOSR-TR- 85-0381	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Computational Methods in Advanced Stress and Durability Analyses	5. TYPE OF REPORT & PERIOD COVERED: FINAL: 15 NOV 80-01 DEC 83
	6. PERFORMING ORG. REPORT NUMBER: GIT-CACM-SNA-84-48
7. AUTHOR(s): S.N. Atluri	8. CONTRACT OR GRANT NUMBER(s): AFOSR 81-0057
9. PERFORMING ORGANIZATION NAME AND ADDRESS: GEORGIA INSTITUTE OF TECHNOLOGY, ATLANTA, GA 30332	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F, 2307/B2
11. CONTROLLING OFFICE NAME AND ADDRESS: AirForce Office of Scientific Research/NA, Bolling Air Force Base, D.C. 20332-6448	12. REPORT DATE: November 1984
	13. NUMBER OF PAGES: 13
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

DTIC ELECTE MAY 23 1985 S D B

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Stress Analysis, Durability Analysis, Fracture, Fatigue, Finite Elements, Boundary Elements, Surface Flaws, Shell Theory, Finite Deformation, Kinematic Modes, Hybrid/Mixed Elements, Stability Conditions, Stokes Flow, Navier Stokes Equations, Mixed Methods for Flow Analysis, Objective Time Integration, Plate Elements, Hole Elements, Laminated Composites. (Continued on Reverse Side)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this report, research accomplished under AFOSR grant 81-0057 titled "Computational Methods in Advanced Stress and Durability Analyses" is summarized. A list of about 50 publications in open literature arising out of this research is given. Salient conclusions from this research are briefly given.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

cont'd

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

19. Fracture of Composites, Alternating Method for Surface Flaws, Path-independent Integrals, Creep Crack Growth, Moving-Element Methods, Dynamic Fracture.

Accession For		
NTIS GRA&I	☒	
DTIC TAB	☐	
Unannounced	☐	
Justification	PER CALL JC	
By		
Distribution/		
Availability Codes		
Dist	Avail and/or Special	
A-1		

DTIC COPY INSPECTED 3

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

AFOSR-TR- 85-0381

FINAL SCIENTIFIC REPORT

AFOSR Grant 81-0057

"Computational Methods in
Advanced Stress and Durability Analysis"

GEORGIA INSTITUTE OF TECHNOLOGY

CENTER FOR THE ADVANCEMENT OF COMPUTATIONAL MECHANICS

85 4 23 027

FINAL SCIENTIFIC REPORT

AFOSR Grant 81-0057

"Computational Methods in
Advanced Stress and Durability Analysis"

Supported by

Air Force Office of Scientific Research
Building 410
Bolling Air Force Base D.C. 20332
(Dr. Anthony Amos, Program Manager)

Principal Investigator
S.N. Atluri
Regents' Professor of Mechanics
Center for the Advancement of Computational Mechanics
School of Civil Engineering
Georgia Institute of Technology, Atlanta, Georgia 30332

November 1984

I. Introduction:

In this report, research accomplished under AFOSR grant 81-0057, titled "Computational Methods in Advanced Stress and Durability Analyses" during the period 15 November 1980 - 1 Dec. 1983 ~~February 1984~~, is summarized. The research was performed at the Center for the Advancement of Computational Mechanics, Georgia Institute of Technology, with S.N. Atluri, Regents' Professor of Mechanics, as the principal investigator.

The report is organized as follows. In Section II, the results of research on computational methods for advanced stress analysis are summarized. In Section III, the results of research pertaining to fracture and durability analyses are summarized. A list of publications and presentations arising out of this research is given in Section IV. ~~Finally,~~ Section V contains a list of students and post-doctoral fellows who participated in this research effort. Originator supplied keywords include: DD1473 it ii (Block 19)

II. Computational Methods for Advanced Stress Analysis:

In Ref. [1], a significant development of a new shell theory has been presented, wherein attention has been focused on: (i) definitions of alternate measures of 'stress-resultants' and stress-couples in a finitely deformed shell (finite mid-plane stretches as well as finite rotations), and mixed variational principles for shells, undergoing large mid-plane stretches and large rotations, in terms of a stress function vector and the rotation tensor. In doing so, both types of polar-decomposition of the shell deformation gradient were considered. Ref. [1] contains a comprehensive discussion of the shell constitutive relations, objective stress measures, and objective strain measures. This new theory has been applied in the development and implementation of hybrid-mixed finite element methods for

finite deformation analysis of plates and shells in Refs. [2-7].

An area of significant research accomplishment has been the analysis of, and remedies for, kinematic modes in hybrid-stress finite elements and the rational selection of stable, invariant stress-fields [8]. fundamental studies into the stability of hybrid/mixed finite element methods for Navier-Stokes equations in solid/fluid mechanics have been carried out [9]. Symmetry group theory has been used to guarantee the essential non-orthogonality of the stress and strain fields, resulting in a set of least-order selections of stable invariant stress polynomials for three-dimensional elements [10]. The theory of the least-order stable stress fields has been successfully applied in the development of isoparametric curvilinear 2- and 3-D hybrid stress elements which have been demonstrated to be far superior in performance to the standard displacement elements [11]. The general theory of the use of stress functions and asymptotic solutions in finite element analysis of continua has been comprehensively discussed in [12].

The progress made in the basic theory of hybrid and mixed finite element methods in solid and fluid mechanics, and their advantages over standard displacement methods in linear as well as nonlinear problems, has been succinctly summarized in [13]. A philosophically broader class of hybrid methods of analysis, involving a combination of analytical-numerical methods, numerical-experimental methods, and a combination of two or more distinctly different numerical schemes, has been discussed in [14].

A major summary work dealing with present status and future directions in computational solid mechanics (finite elements and boundary elements) has been prepared [15]. In this work, the following topics were discussed: (i) LBB conditions for general finite element methods; (ii) least-order, stable, hybrid/mixed elements; (iii) use of symbolic manipulation; (iv) adaptive mesh refinement; (v) boundary-element methods for linear elasticity, as well as for

finite strain problems of inelastic materials; (vi) constitutive modeling of inelastic material behavior; and (vii) control of dynamic response of solids.

In Ref. [16], computational techniques, which preserve the objectivity of incremental constitutive relations, for finite elastic or inelastic materials, for finite time steps, during which the material elements may undergo finite rotations, have been presented and their efficiency has been demonstrated.

The theoretical background of mixed finite element models, in general for nonlinear problems and in particular for plate bending problems, has been examined in detail [17]. It was concluded that mixed finite element formulations, wherein the interpolants for stress fields satisfy only a part of the domain equilibrium equations, are not only consistent from a theoretical viewpoint, but are also preferable from an implementation viewpoint. A new mixed finite element for plate-bending analysis has been developed [18], and its performance has been shown to be superior to most elements in existing literature.

Another area of significant research accomplishment has been in the area of development of finite element methods based on complementary work principles for problems with constraint such as incompressibility in solid and fluid mechanics. Hybrid finite element methods for analysis of incompressible viscous creeping flow (Stokes flow), analogous to the problem of incompressible elasticity, has been successfully developed [19,20] and has been demonstrated to be far superior to the currently popular methods based on reduced-integration-penalty formulations involving only kinematic variables. Fundamental studies pertaining to the stability and convergence of these hybrid methods to treat material incompressibility have been completed [21].

A formulation of a mixed finite element method for the analysis of unsteady, convective, incompressible viscous flow has been presented [22] in which: (i) the deviatoric stress, pressure, and velocity are discretized in

each element; (ii) the deviatoric stress and pressure are subject to the constraint of homogeneous momentum balance condition in eac' element, a priori; and (iii) the convective acceleration is treated by the conventional Galerkin approach. A fundamental analysis of the stability of the scheme is also presented. The method has been shown to be a superior alternative to the popular reduced-integration penalty methods in a variety of Navier-Stokes flow problems [23]. An analysis of flow over a backward facing step using the present assumed stress mixed method has been presented in [24]. While extending the concept of using the complementary energy approach to treat problems of incompressibility, certain new algorithms for analyzing large strain plasticity were presented in [25].

III. Computational Methods for Advanced Fracture and Durability Analysis:

In Ref. [26], the development of 'special-hole-elements' to enable an efficient and accurate analysis of stress concentration around holes in angle-ply laminates has been presented. In these 'hole-elements', the development of which is based on a modified complementary energy principle, the analytical asymptotic solutions for the stress-state near the hole are embedded. the fully 3-D stress state in the laminate is accounted for. This procedure leads to a very efficient and accurate evaluation of stress concentration around holes in laminates. Later, in Ref. [27], a simplified method for estimation of stress-intensity factors for through-cracks, or for stress-concentration factors for holes, in angle-ply laminates has been presented. The simplicity of this method [27] makes it a practical and viable design tool.

One of the major and significant accomplishments of this research has been the development of a highly accurate, yet one of the most computationally efficient, technique for the analysis of surface flaws in aerospace structures. This is the enhanced alternating technique which employs the

complete solution for an embedded elliptical crack in an infinite solid and subject to arbitrary tractions on the crack-surface as derived in the current research [28,29]. The general procedure for evaluating the necessary elliptic integrals has been systematically derived [29]. The finite element alternating technique that is thus developed leads to a highly accurate yet inexpensive method for analyzing surface flaws in complex three-dimensional geometries of aerospace structural components. This new method has been extensively tested in its ease of applicability and accuracy in solving problems of surface flaws near fastener holes in aircraft attachment lugs [30] and in the analysis of surface flaws near the inner and outer surfaces of pressure vessels [31]. The analytical solution for the embedded elliptical crack in an infinite solid has recently been extended to the case of multiple coplanar as well as nonplanar elliptical cracks in an infinite solid subject to arbitrary crack-free tractions [32]. This analytical solution for multiple embedded flaws has been successfully implemented in a finite element alternating technique for analyzing multiple surface flaws in complicated geometries [33] — thus rendering the multiple crack 3-D problem feasible for analysis for the first time in literature. These solutions for multiple surface flaws in complex geometries were also derived in the more readily usable form of K-factor influence functions for various types of polynomial crack-face loadings [34].

The work on 3-dimensional fracture mechanics has been documented in a comprehensive summary [35] to appear in a forthcoming book [36] on computational fracture mechanics. Invited summaries of this work have also appeared in [37,38].

In Ref. [39], an analysis of fatigue growth of cracks in center-cracked panels and cold-worked fastener holes was presented, and a quantitative evaluation of the effect of cold-working on fatigue life was presented in

detail.

In Ref. [40], a comprehensive study of certain path-independent integrals, of relevance in the presence of cracks, in elastic and inelastic solids was presented. A new set of crack-tip parameters, T^* and ΔT^* and their path-independent integral representations, were newly given. The physical interpretations of these integrals, either in terms of crack-tip energy release rates or simply energy differences in two comparison cracked bodies, were explored. The use of the rate integral (ΔT) was explored in the analysis of steady as well as non-steady state creep crack growth in structures operating under elevated temperature environments [41,42].

In [43] a path-independent integral, J', which has the precise meaning of energy release rate per unit crack-extension in elasto-dynamic crack propagation, was introduced. Also, the general asymptotic solution in mixed-mode dynamic crack propagation, and the relation of the J' integral to the mixed-mode dynamic stress-intensity factors, were given [43]. Simple numerical methods based on a moving mesh of non-singular isoparametric elements were devised and extensively tested [44,45] to analyze dynamic crack propagation using the J' integral.

A general summary of path-invariant integrals in dynamic fracture and the distinguishing features of the J' integral were given in [46].

The moving-mesh finite element algorithms developed for analyzing dynamic crack propagation have been extensively tested in their analysis and predictive capability modes [47]. Based on these studies, a simple formula for determining the dynamic k-factor near a propagating crack-tip, through extrapolation from the measured crack-mouth opening displacement, has been given [48].

A number of presentations based on the above research were made. These are listed in Section IV.

IV. List of Publications and Presentations:

IV.A Publications:

1. S.N. Atluri, "Alternate Stress and Conjugate Strain Measures, and Mixed Variational Formulations Involving Rigid Rotations, for Computational Analyses of Finitely Deformed Solids, with Application to Plates and Shells - Part I: Theory", Computers and Structures, Vol. 18, No. 1, 1983, pp. 93-116.

2. H. Murakawa and S.N. Atluri, "Finite Deformations, Finite Rotations and Stability of Plates: A New Complementary Energy-Finite Element Analysis", Proceedings of 22nd AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, Atlanta, Georgia, April 1981, pp. 7-15.

3. H. Murakawa, K. W. Reed, S. N. Atluri, and R. Rubinstein, "Stability Analysis of Structures Via a New Complementary Energy Method", Computers & Structures, Vol. 13, 1981, pp. 11-18.

4. N. Fukuchi and S.N. Atluri, "Finite Deformation Analysis of Shells: A Complementary Energy-Hybrid Method", Nonlinear Finite Element Analysis of Plates and Shells, AMD-Vol. 48, ASME, NY, pp. 233-247, 1981.

5. N. Fukuchi and S.N. Atluri, "Finite Deformation Analysis of Shells: A Hybrid Finite Element Method Based on Assumed Stress-Function Vector and Rotation Tensor", Proceedings 23rd AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, Lake Tahoe, pp. 205-215, 1983.

6. E. F. Punch and S. N. Atluri, "Optimal, Stable, and Invariant Hybrid Elements; Large Rotation Plate and Shell Analysis", Advances in Aerospace Structures, ASME-AD-Vol. 3, 1983.

7. E. F. Punch and S. N. Atluri, "Least-Order, Stable, Invariant Isoparametric Hybrid-Finite elements for Linear Continua and Finitely Deformed Plates, Proceedings 25th AIAA/ASME/ASCE/AHS Structures, Structural Dynamics and Materials Conference, Palm Springs, California, May 1984.

8. R. Rubinstein, E. F. Punch, and S.N. Atluri, "An Analysis of, and Remedies for, Kinematic Modes in Hybrid-Stress Finite Elements: Selection of Stable, Invariant Stress Fields", Computer Methods in Applied Mechanics and Engineering, Vol. 38, 1983, pp. 63-92.

9. C-T. Yang, R. Rubinstein, and S.N. Atluri, "On some Fundamental Studies into the Stability of Hybrid/Mixed finite element Methods for Navier/Stokes Equations in Solid/Fluid Mechanics, Proceedings of 6th Invitational Symposium on Unification of Finite Elements-Finite Differences and Calculus of Variations, (H. Kardestuncer, Editor), 1982, pp. 24-76.

10. E.F. Punch and S.N. Atluri, "Applications of Isoparametric Three-Dimensional Hybrid-Stress Finite Elements with Least-Order Stress Fields", Computers & Structures, Vol. 19, No. 3, 1984, pp. 409-430.

11. E.F. Punch and S.N. Atluri, "Development and Testing of Stable, Invariant, Isoparametric Curvilinear 2- and 3-D Hybrid Stress Elements", Computer Methods in Applied Mechanics and Engineering, 1984 (to appear).

12. S.N. Atluri, H. Murakawa, and C. Bratianu, "Use of Stress Functions and Asymptotic Solutions in FEM Analysis of Continua", New Concepts in Finite Element Analysis, ASME AMD Vol. 44 (T.J.R. Hughes et al., Editors), 1981, pp. 11-28.

13. S.N. Atluri, P. Tong, and H. Murakawa, "Recent Studies of Hybrid and Mixed Finite Element Methods in Mechanics", Hybrid and Mixed Finite Element Methods (S.N. Atluri, R.H. Gallagher, and O.C. Zienkiewicz, Editors), J. Wiley & Sons, 1983, pp. 51-72.

14. S.N. Atluri and T. Nishioka, "Hybrid Methods of Analysis" in Unification of Finite Element Methods (H. Kardestuncer, Editor), North-Holland Publishers, 1984, pp. 65-96.

15. S.N. Atluri, "Computational Solid Mechanics (Finite Elements & Boundary Elements): Present Status and Future Directions", Invited General Lecture, 4th International Conference on Applied Mathematical Modeling, Tainan, Republic of China.

16. R. Rubinstein and S.N. Atluri, "Objectivity of Incremental Constitutive Relations over Finite Time Steps in Computational Finite Deformation Analyses", Computer Methods in Applied Mechanics & Engineering, Vol. 36, 1983, pp. 277-290.

17. D Karamanlidis and S.N. Atluri, "Mixed Finite Element Models for Plate Bending Analysis: Theory", Computers & Structures, Vol. 19, No. 3, 1984, pp. 431-445.

18. D. Karamanlidis, H.L. The, and S.N. Atluri, "Mixed Finite Element Models for Plate Bending Analysis: A New Element and Its Applications", Computers & Structures, 1984 (in press).

19. C. Bratianu and S.N. Atluri, "A Hybrid Finite Element Method for Stokes Flow: Part I - Formulation and Numerical Studies", Computer Methods in Applied Mechanics & Engineering, Vol. 36, 1983, pp. 23-37.

20. C. Bratianu, L-A. Ying, and S.N. Atluri, "Analysis of Stokes Flow by a Hybrid Method" in Finite Elements in Flow Problems (T. Kawai, Editor), University of Tokyo Press, 1982, pp. 981-991.

21. L-A. Ying and S.N. Atluri, "A Hybrid Finite Element Method for Stokes Flow: Part II - Stability and Convergence Studies", Computer Methods in Applied Mechanics & Engineering, Vol. 36, 1983, pp. 39-60.

22. C-T. Yang and S.N. Atluri, "An 'Assumed Deviatoric Stress-Pressure-Velocity' Mixed Finite Element Method for Unsteady, Convective, Incompressible, Viscous Flow: Part I - Theoretical Development", International Journal for Numerical Methods in Fluids, Vol. 3, 1983, pp. 377-398.

23. C-T. Yang and S.N. Atluri, "An 'Assumed Deviatoric Stress-Pressure-Velocity' Mixed Finite Element Method for Unsteady, Convective, Incompressible, Viscous Flow: Part II - Computational Studies", International Journal for Numerical Methods in Fluids, Vol. 4, 1984, pp. 43-69.

24. C-T. Yang and S.N. Atluri, "An Analysis of Flow over a Backward Facing Step by an Assumed Stress Mixed Finite Element Method" in Numerical Methods for Laminar and Turbulent Flow (C. Taylor, Editor), Pineridge Press, Swansea, 1983.

25. S.N. Atluri, "New Developments in Numerical Analysis of Large Deformation Plasticity, Applied to Geomechanics" in Numerical Methods in Geomechanics, Balkema Press, Netherlands, 1983.

26. T. Nishioka and S.N. Atluri, "Stress Analysis of Holes in Angle-Ply Laminates: An Efficient 'Assumed Stress Special-Hole-Element' Approach and a Simple Estimation Method", Computers & Structures, Vol. 15, No. 2, 1982, pp. 135-147.

27. T. Nishioka and S.N. Atluri, "A Simple Estimation Method of Stress Intensity Factors for Through-Cracks in Angle-Ply Laminates", Engineering Fracture Mechanics, Vol. 16, No. 4, 1982, pp. 573-583.

28. T. Nishioka and S.N. Atluri, "A Major Development Towards a Cost-Effective Alternating Method for Fracture Analysis of Steel Reactor Pressure Vessels", Transaction 6th International Conference on Structural Mechanic in Reactor Technology, Paper G1/2, Paris, 1981.

29. T. Nishioka and S.N. Atluri, "Analytical Solution for Embedded Elliptical Cracks, and Finite Element Alternating Method for Elliptical Surface Flaws, Subjected to Arbitrary Loadings", Engineering Fracture Mechanics, Vol. 17, No. 3, 1982, pp. 247-268.

30. T. Nishioka and S.N. Atluri, "An Inexpensive 3-D Finite Element-Alternating Method for the Analysis of Surface Flawed Aircraft Structural Components", AIAA Journal, Vol. 21, No. 5, 1983, pp. 749-758.

31. S.N. Atluri and T. Nishioka, "Analysis of Surface Flaws in Pressure Vessels by a New 3-Dimensional Alternating Method", Journal of Pressure Vessel Technology, ASME, Vol. 104, 1982, pp. 299-307.

32. P.E. O'Donoghue, T. Nishioka, and S.N. Atluri, "Multiple Coplanar Embedded Elliptical Cracks in an Infinite Solid Subject to Arbitrary Crack Face Tractions", International Journal for Numerical Methods in Engineering, 1984 (In Press).

33. P.E. O'Donoghue, T. Nishioka, and S.N. Atluri, "Multiple Surface Cracks in Pressure Vessels", Engineering Fracture Mechanics, 1984 (In Press).

34. P.E. O'Donoghue, T. Nishioka, and S.N. Atluri, "Analysis of Interaction Behaviour of Surface Flaws in Pressure Vessels", Journal of Pressure Vessel Technology, ASME, 1984 (In Press).

35. S.N. Atluri and T. Nishioka, "Computational Methods in 3-Demensional Fracture Analyses", a chapter to appear in Computational Methods in the Mechanics of Fracture, North-Holland Publishers, 1985 (To Appear).

36. S.N. Atluri (Editor), Computational Methods in the Mechanics of Fracture, North-Holland Publishing Co., The Netherlands, 1985 (To Appear).

37. S.N. Atluri, "Current Studies in Inelastic, Dynamic and Three-Dimensional Fracture Analysis" in Fracture Tolerance Evaluation (T. Kanazawa et al., Editors), University of Tokyo Press, 1982, pp. 45-57.

38. S.N. Atluri, "Computational and Theoretical Studies on Dynamic Fracture Mechanics and Three-Dimensional Crack Problems", Proceedings ICF International Symposium on Fracture Mechanics, 1983, pp.1-17.

39. M. Nakagaki and S.N. Atluri, "Analysis of Fatigue Cracks in Center Cracked Panels and Cold-Worked Fastener Holes", ASME Preprint, 82-PVP-24, 1982, 11 pp.

40. S.N. Atluri, "Path-Independent Integrals in Finite Elasticity and Inelasticity, with Body Forces, Inertia, and Arbitrary Crack Face Conditions", Engineering Fracture Mechanics, Vol. 16, No. 3, 1982, pp. 341-362.

41. R.B. Stonesifer and S.N. Atluri, "On a Study of the $(\Delta T)_c$ and C* Integrals for Fracture Analysis Under Non-Steady Creep", Engineering Fracture Mechanics, Vol. 16, No. 5, 1982, pp. 625-643.

42. R.B. Stonesifer and S.N. Atluri, "Moving Singularity Creep Crack Growth Analysis with the $(\Delta T)_c$ and C* Integrals", Engineering Fracture Mechanics, Vol. 16, No. 2, 1982, pp. 769-782.

43. T. Nishioka and S.N. Atluri, "Path-Independent Integrals, Energy Release Rates, and General Solutions of Near-Tip Fields in Mixed-Mode Dynamic Fracture Mechanics", Engineering Fracture Mechanics, Vol. 18, No. 1, 1983, pp. 1-22.

44. T. Nishioka and S.N. Atluri, "A Numerical Study of the Use of Path-Independent Integrals in Elasto-dynamic Crack Propagation", Engineering Fracture Mechanics, Vol. 18, No. 1, 1983, pp. 23-33.

45. T. Nishioka and S.N. Atluri, "Dynamic Crack Propagation Analysis Using a New Path-Independent Integral and Moving Isoparametric Elements", AIAA Journal, Vol. 22, No. 3, 1984, pp. 403-415.

46. S.N. Atluri, "Energy-Release Rates in Dynamic Fracture: Path-Invariant Integrals and Some Computational Studies" in Fracture Mechanics Technology Applied to Material Evaluation and Structural Design (G.C. Sih and R. Jones, Editors), Martinus Nijhoff, 1983, pp. 327-340.

47. T. Nishioka and S.N. Atluri, "Numerical Analysis of Dynamic Crack Propagation: Generation and Prediction Studies", Engineering Fracture Mechanics, Vol. 16, No. 3, 1982, pp. 303-332.

48. S.N. Atluri and T. Nishioka, "A Method for Determining Dynamic Stress Intensity Factors from COD Measurement at the Notch Mouth in Dynamic Tear Testing", Engineering Fracture Mechanics, Vol. 16, No. 3, 1982, pp. 333-339.

IV.B. Presentations

49. S.N. Atluri, Invited Plenary Lecture, "Recent Studies on Energy Integrals and Their Applications", International Congress on Fracture, ICF6, New Delhi, December 4-10, 1984.

50. S.N. Atluri, Invited General Lecture, "Computational Solid Mechanics: Its Present Status and Future Prospects", 4th International Conference on Applied Mathematical Modelling, Tainan, R.O.C., December 27-31, 1984.

51. S.N. Atluri, Invited Lecture, "Crack-Tip Parameters in Dynamic Fracture", International Conference on Dynamic Fracture, San Antonio, November 1984.

52. S.N. Atluri, Invited General Lecture, "Advances in Computational Mechanics", U.S.-China Workshop on Computational Mechanics, sponsored by U.S. NSF and PRC Ministry of Education, Dalian, August 1983.

53. S.N. Atluri, Invited Lecture, "Hybrid Finite Element Methods for Flow Problems", International Conference on Finite Elements in Fluid Flow, Chero University, Tokyo, Japan, July 1982.

54. S.N. Atluri, Invited Lecture, "Path-Invariant Integrals in Dynamic Fracture", International Conference on Fracture Mechanics, Melbourne, Australia, August 1982.

55. S.N. Atluri, Invited Lecture, "Hybrid Methods of Analysis", 7th Invitational Symposium on Unification of Finite Element Methods, dedicated to J. H. Argyris, Storrs, Connecticut, May 1984.

56. S.N. Atluri, Invited Lecture, "Fundamental Studies of Stability of Hybrid/Mixed Finite Element Methods", Storrs, Connecticut, May 1982.

57. S.N. Atluri, Invited Lecture, "Studies on 3-Dimensional Fracture Analysis", U.S.-Japan Joint Seminar on Fracture Tolerance Evaluation, Honolulu, Hawaii, December 1981.

In addition, about 25 invited as well as contributed papers were presented at national conferences of ASME, ASCE, and AIAA and at several universities in U.S.A. and Japan.

V. List of Participants in Research:

a. S.N. Atluri, Principal Investigator
Regents' Professor of Mechanics
Georgia Institute of Technology

b. Edward F. Punch, Graduate Student
Received Ph.D: 1983, Georgia Tech
Currently: General Motors Research Labs, Warren, Michigan

c. C-T. Yang, Graduate Student
Received Ph.D: 1983, Georgia Tech
Currently: Detroit Diesel Allison, Indianapolis, Indiana

d. P.E. O'Donoghue, Graduate Student
Ph.D Student, in progress

e. R.B. Stonesifer, Graduate Student
Received Ph.D: 1981, Georgia Tech
Currently: President, Computational Mechanics, Inc.
College Park, Pennsylvania

f. R. Rubinstein, Post-Doctoral Fellow
Currently: General Electric Co., Cincinnati, Ohio

g. T. Nishioka, Post-Doctoral Fellow and later Visiting Assistant Professor
Currently: Returned to Japan as Associate Professor
Kobe University of Mercantile Marine

h. D. Karamanlidis, Post-Doctoral Fellow from Germany
(Primarily supported by German Science Foundation)
Currently: Visiting in University of Rhode Island

i. J. Webb, Technical typing and administrative assistance

END

FILMED

6-85

DTIC